Renewable and Sustainable Energy Reviews 28 (2013) 385–391

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Electric energy micro-production in a rural property using biogas as primary source

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ARTICLE INFO

Article history:
Received 18 April 2012
Received in revised form
18 July 2013
Accepted 20 July 2013
Available online 30 August 2013

Keywords:
Biodigestors
Pig farming
Renewable energy
Biogas

ABSTRACT

The generation of electric energy distributed throughout Brazil's rural area contributes in the supply and logistics of energy production all over the country. This work aimed to analyze biogas production from swine waste and the generation of electric energy using biogas as primary source. Biogas was produced in São Miguel do Iguaçu - Paraná, Brazil, in a rural property which uses two biodigesters to produce biogas, whose electric conversion is performed in an engine-generator set of 100 kVA. With an average of 4672 housed animals, 554 $Nm^3\,day^{-1}$ of biogas were used in the generation of 847 $kWh\,day^{-1}$ of electricity and the rest was incinerated in a flare. The average specific consumption of biogas in the engine-generator set was 0.68 $m^3\,kW\,h^{-1}$ and its efficiency was 22.21%. The cost of electric energy production using biogas was 0.12 R$ $kW\,h^{-1}$ and the cost of the supplier's electricity was 0.14 R$.$kWh^{-1}$. One can observe the economical feasibility of electricity production from biogas, even without receiving carbon credits.

Contents

1. Introduction

The economical development resulted in an increased demand for several kinds of energy in Brazil and around the world due to constant machinery evolution and the popularization of equipment. Between 1973 and 2006 energy supply around the world rose from 6,115 million TOE (tonnes of oil-equivalent) to 11,741 million TOE [1].

Even though Brazil has an energy supply that depends on non-renewable energies such as oil, natural gas and coal, the renewable sources, such as biomass, hydraulics, firewood, charcoal, lye, among others, are responsible for 44.1% of the domestic supply of energy [2].

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1364-0321/$ - see front matter
http://dx.doi.org/10.1016/j.rser.2013.07.035

Pao and Fu [3] highlight that most developing countries started identifying and implementing programs and laws to improve the infrastructure of rural renewable energy markets, making them more attractive to investors, what results in bigger investments and leads to a brighter future for renewable energy.

The increase of fuel consumption rates helps to increase fossil fuel usage, strengthening its problems. Alternative energy sources, mainly biomass, tend to bring environmental sustainability, reducing part of the problems related to energy.

Biogas production from swine waste contributes to environment protection, as in the reduction of CO_2 emissions due to the substitution of fossil fuels and decrease of methane (CH_4) released in the atmosphere [4]. The substitution of fossil fuels by renewable energy sources helps the atmosphere′s carbon cycle, avoiding the release of carbon stuck in geological strata.

In Brazil, the PROINFA (Program of Incentive to Alternative Sources of Energy) aims to stimulate the production of decentralized electric energy by independent and freelance producers. The extension of thermoelectric generation with biomass is one of PROINFA′s goals. In that sense, there came up an opportunity for systems of electric energy generation that use biogas as primary energy source to be implemented in rural and agro industrial properties, for self-consumption and distribution to the concessionaire′s network, in case of surplus [5].

Even with all the advantages of using renewable sources, its implementation is still limited normally by its technical-economical feasibility due to high costs and the maintenance of the production system and bioenergy conversion.

This work aimed to determine biogas production in a swine farm, evaluate electricity generation potential and cost of production by means of field research in a case study.

2. Biogas

Biogas is produced from biomass anaerobic biodegradation, lack of oxygen and anaerobic microorganism presence. Anaerobic digestion is a consequence of a series of metabolic interactions among several groups of microorganisms [6].

It is basically composed of 40–75% methane (CH_4), 25–60% carbon dioxide and traces of hydrogen sulfide, nitrogen, hydrogen, carbon monoxide and oxygen [7–11], its concentration and volume are influenced by the source of organic matter. Residues containing bigger organic concentration generate biogas richer in methane [12,13].

Methane′s calorific value is 8,500 kcal m^{-3}, therefore the concentration of methane in biogas is directly related to calorific power and biogas density. Energy potential in fuels is determined by the inferior calorific value. Highly purified biogas can achieve up to 12,000 kcal m^{-3} [14].

2.1. Microgeneration of electricity with biogas

According to ANEEL (Brazilian Electricity Regulatory Agency) [15], the distributed micro-production is the electric energy power station with capacity lower or equal to 100 kW and using renewable energy sources such as solar, wind, biomass, hydraulic or cogeneration plants, connected to the supplier′s low voltage network by means of energy consumption units.

2.2. Motors electric power generators biogas

The transformation of chemical energy into biogas can be effective using internal combustion engines [16] states that thermal engines of internal combustion are equipments in which the incoming mixture is burnt and its thermal energy is transformed into mechanical energy.

A power generator must be connected to the engine axis for this result. If the power generation is connected to the supplier′s network, it is necessary to install a control board to make the connection and protect the network and its equipments.

According to [17] the efficiency of biogas conversion into electricity with OTTO cycle internal combustion engines is 25%, and biogas inferior calorific power is 6.5 kWh/m^{-3} (60% CH_4).

3. Materials and methods

3.1. Description of the research area

Colombari Poultry Farm is located at Linha Marfim, in the municipality of São Miguel do Iguaçu, latitude 25°20′53 South and longitude 54°14′16 West, in the state of Paraná. It works with confined creation system. Biomass generation is directly linked to handling factors, water supply system, conditioning and cleaning systems. In the output tubing, the effluent is directed to a dunghill that stores the biofertilizers, which will be used in crops.

The generation of electric energy is accomplished with the use of a motor-generator set with 100 kVA, protection system and command board. It is interconnected to the distribution network, for the commercialization of the excesses.

3.2. Data collection

To measure the biogas burnt in the flare, a gauge model Roots Meter Series B3 was used [18], with measuring levels from 22,6 to 1,600 m^3 day^{-1}. For biogas consumption of the engine-generator set ($m^3\ h^{-1}$), a thermal dispersion flow gauge model Thermatel TA2 Enhanced was used [19], with measuring levels ranging from 0.51 to 85 ($m^3\ h^{-1}$), from November 2010 to June 2011.

Data were collected at [20] referring to room temperature, to analyze the relation between housed swine and biogas production and environment temperature.

Biogas quality (methane percentage) was analyzed using Drager X-am 7000 [21]. Quality control was registered from April 15 to May 24, with 4 daily samplings. A SMART METER T in conjunction with its SOFTWARE SMART ANALYZER T was used in the property′s electricity production; it allows graphic and reports generation according to ANEEL′s resolution 505 [22]; data were collected between March 1 and 14, 2011, with intervals of 15 min.

From the fuel consumption ($m^3\ h^{-1}$), active power (kW) and time (h) data it was possible to calculate specific fuel consumption in $m^3\ kW\ h^{-1}$ [23]. The specific fuel consumption (SFC), in $m^3\ kW\ h^{-1}$, is given by

$$SFC = \frac{BCH}{AP} \tag{1}$$

in which BCH is biogas consumption per hour ($m^3\ h^{-1}$) in the engine-generator set and AP is the active power (kW).

3.2.1. Conversion efficiency of biogas for electricity

To check the performance (in other words, how efficient the transformation is) of the engine-generator set, at the property, using gas as primary source, Eq. 2 was used.

$$\eta = \frac{AO}{BCH.ICP} \tag{2}$$

where η is the engine-generator system efficiency; ICP is the biogas inferior calorific power (kWh m^{-3}).

Data for active power (kW) in the set were gathered by means of control panel WOODWARD model GCP – 20 [24] from the generator set.

The energy efficiency test was performed on April 21, 2011 simulating the engine-generator set operating at a load ranging

from 10 to 100%, collecting data such as active power (kW), biogas quality and consumption ($m^3\,h^{-1}$).

3.3. Costs of biogas production and energy

The produced biogas is used to generate electricity for approximately 10 h a day and the electric energy cost is deducted from the investment on the biodigester in the scenario in which the property produces electric energy and does not receive carbon credits.

Electric energy production cost was calculated by using as capital recovering factor (CRF) the annual discount rate from governmental Program ABC to low carbon agriculture which is 5.5% [25]. Maintenance and operating cost of the engine-generator set was 2%. To calculate amortization on the investment it was necessary to take into account a period between 5 and 20 years. On the annual electricity generation, US$ 7,684.73 were deducted, concerning to the power consumed by the property. Biogas production was not considered, once the property already included a biodigester, for being a mandatory equipment to handle swine waste. Also, incineration of biogas on flare was replaced by electricity generation. According to Aneel [26] the amount paid by COPEL to micro-producers of energy, based on the Annual Reference Value (RV), is US$ 70.00 per mW/h.

Eq. (3) was used in order to obtain the electricity production cost.

$$\mathrm{CBGE} = \frac{\mathrm{ABC} + \mathrm{AIE}}{\mathrm{EG}} \tag{3}$$

in which CBGE - Cost of biogas generated electricity (US$ $kW\,h^{-1}$), ABC - annual biogas cost (US$ $year^{-1}$) and EG – Electricity generated by biogas plant (kWh $year^{-1}$), AIE –Annual investment in the engine-generator set (US$ $year^{-1}$).

$$\mathrm{AIE} = \mathrm{CIM}{*}\mathrm{CRF} + \frac{\mathrm{CIM}{*}\mathrm{OM}}{100} - \mathrm{ACG} \tag{4}$$

$$\mathrm{ABC} = \mathrm{BP}{*}\mathrm{BCM} \tag{5}$$

in which CIM - cost of investment in the engine-generator set (US$), OM — Operation and Maintenance costs (%), BP — Biogas production cost (US$ m^3) and BCM — Biogas consumption by the engine-generator set ($m^3\,year^{-1}$) and ACG — Annual cost with network electricity (US$ $year^{-1}$) or cost avoided on energy purchase.

Electricity production (EP) is given by

$$\mathrm{EP} = \mathrm{PNP}{*}T \tag{6}$$

where PNP – plant nominal power (kW), T — annual plant availability (h $year^{-1}$).

Capital recovery factor (CRF) is shown

$$\mathrm{CRF} = \frac{j(1+j)^n}{(1+j)^{n-1} - 1} \tag{7}$$

where j — discount rate (%/year) and n — years of amortization. Biogas production cost is given as BPC — (US$ $year^{-1}$) and ABP — Annual biogas production ($m^3\,year^{-1}$).

The cost of production of biogas is given by

$$\mathrm{CB} = \frac{\mathrm{ICB}}{\mathrm{ABP}} \tag{8}$$

ICB — investment cost on biodigester (US$) and ABP — Annual biogas production ($m^3\,year^{-1}$).

$$\mathrm{CIB} = \mathrm{ABC} \cdot \mathrm{FRC} + \frac{\mathrm{CIB} \cdot \mathrm{OM}}{100} - \mathrm{GCC} \tag{9}$$

where CIB — Cost of investment in the digester (US $) and PAB — Annual production of biogas ($m^3\,year^{-1}$) and GCC is the gain from carbon credit (US $ $year^{-1}$).

4. Results

4.1. Considerations on biogas production at the property.

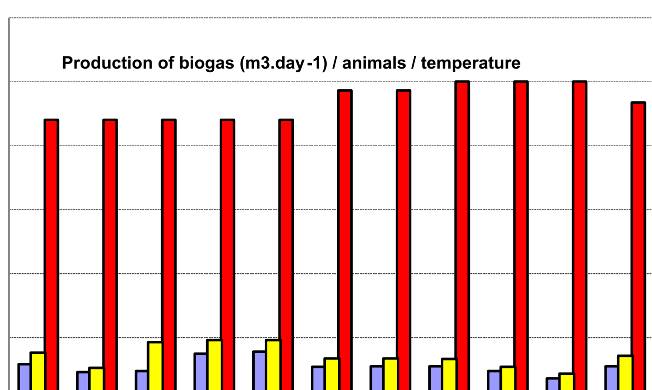
Fig. 1 shows the monthly average of daily biogas production ($m^3\,day^{-1}$) according to the amount of housed swine and daily animal biogas production ($m^3\,day^{-1}\,animal^{-1}$).

The daily average of biogas was 554 $m^3\,day^{-1}$ to an average of 4673 housed animals, at a room temperature of 22.11 °C, therefore, an average production of 0.12 m^3 day per animal.

July and August were the months in which the number of housed animals was higher, that is 5000 pigs, however such months presented the lowest biogas production at the property: 474 and 360 $m^3\,day^{-1}$. This low production occurs due to low temperature, showing less efficiency on hydraulic retention time in months in which room temperature is lower. Fig. 2 shows a biogas daily production curve ($m^3\,day^{-1}$) x temperature (°C), registered by [17].

In January, with an average temperature of 26° C; the production in the following month was 750 ($m^3\,day^{-1}$) of biogas for the same amount of housed pigs.

Fig. 3 shows methane concentration on biogas, ranging from 57.3 and 61.7%, with an average of 60% methane in biogas. According to [27], biogas inferior calorific power was estimated at 6 kWh m^{-3} for methane concentrations at 60%.



	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Average
Biogas (m3/day)	585	458	474	750	784	544	548	555	475	360	553
Animals	4400	4400	4400	4400	4400	4865	4865	5000	5000	5000	4673
m3 de biogas/animal.dia	0,13	0,09	0,15	0,16	0,16	0,11	0,11	0,11	0,09	0,07	0,12

Fig. 1.

4.2. Evaluation of the generated electricity at the property

Fig. 4 presents data recorded by the electricity analyzer and the average active energy production (kWh day^{-1}) as well as the average electricity production per animal (kWh day^{-1} animal), such data are referent to the 14 days of data recording in March 2011.

The average electricity production was 847 kWh day^{-1}, and an average of 0.19 (kWh day^{-1} $animal^{-1}$) on the analyzed period.

In Fig. 5, the active power (kW) refers to March 9, 2011, a normal working day in which the engine-generator set was turned on at 07:00 a.m. and turned off at 08:45 p.m., working for 13 h and 45 min. It took the engine 15 min to reach 80% (60 kW), then at 08:30 a.m. the load was increased to 100% (76 kW). At 09:45 a.m., it was lowered to 80% again, and at 08:45 p.m., it was shut down.

Fig. 6 shows the average specific consumption (m^3 kWh^{-1}) according to Biogas consumption (m^3 h^{-1}) by the engine X generator power (kW).

The engine consumed an average of 45.5 m^3 h^{-1} biogas for an average power of 66.2 (kW), resulting in an average specific consumption of 0.68 m^3 kWh^{-1}.

Biogas consumption matches the supplier's data, for a power of 76 kW the engine has a consumption of 50 m^3 h^{-1}. Table 1 shows

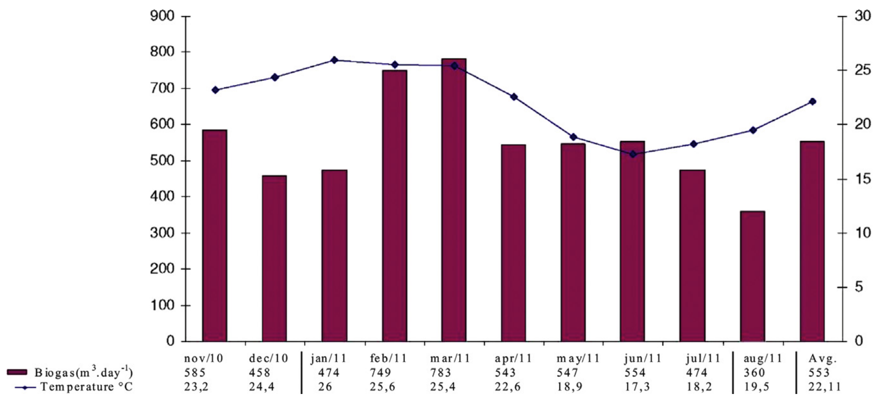


Fig. 2.

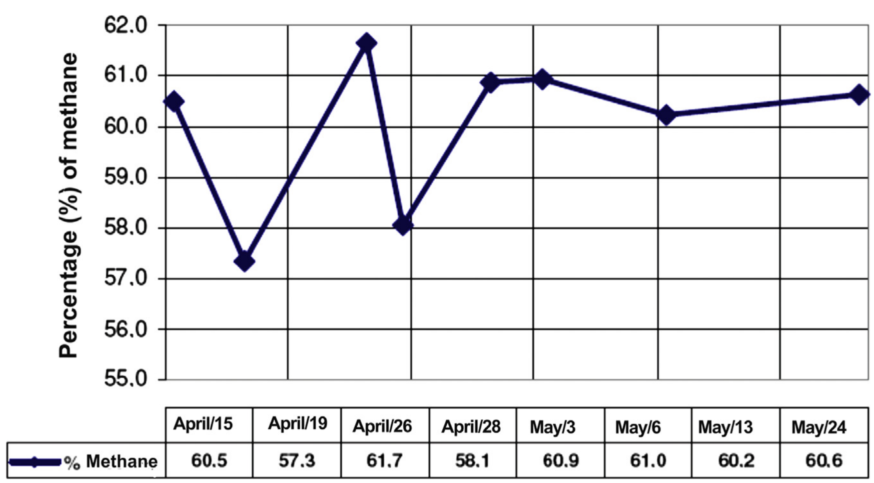


Fig. 3.

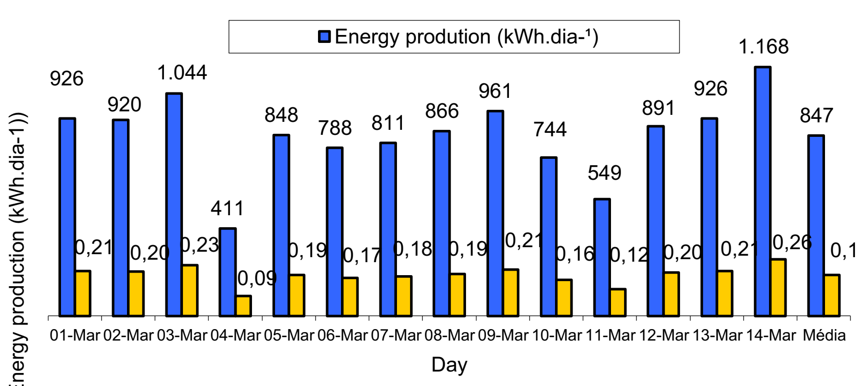


Fig. 4.

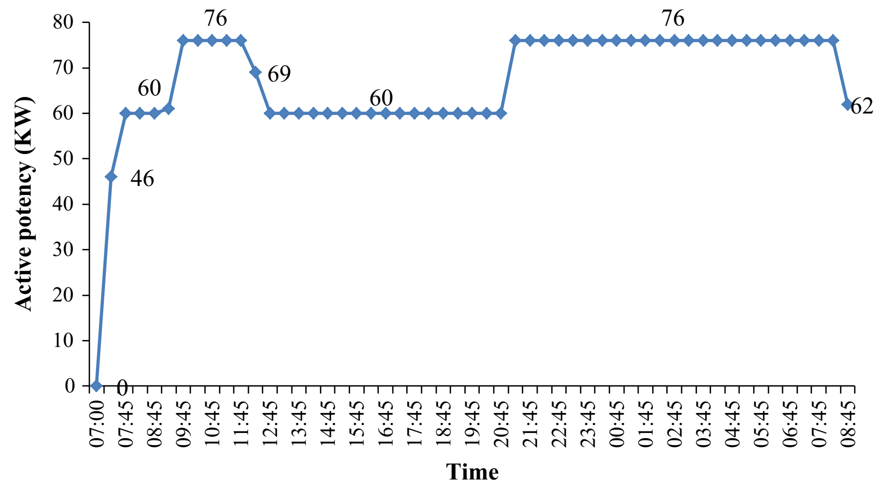


Fig. 5.

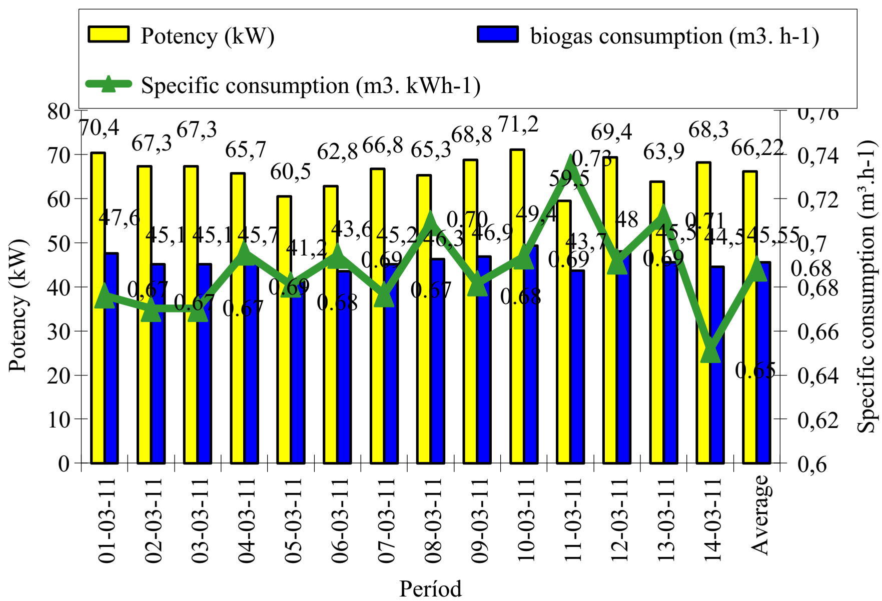


Fig. 6.

values of power (kW), consumption ($m^3\,h^{-1}$) and specific consumption ($m^3\,kWh^{-1}$), for the 14-day sampling period.

4.3. *Efficiency of biogas conversion into electricity*

Fig. 7 shows efficiency (η), according to the experiment varying load (kW).

With the generator operating at a 50% load rate, approximately (40 kW), efficiency in energy conversion was equivalent to 17.28%, whereas at full load, efficiency in energy conversion was 22.21%.

Fig. 8 shows specific consumption on the studied engine-generator set; one may notice that for loads inferior to 50% of the engine's capacity, there is a steep increase in consumption in $m^3\,kWh^{-1}$.

4.4. *Energy production cost*

By comparing electricity production costs with the number of housed animals, it is possible to notice that the producer generates 202.210 $m^3\,year^{-1}$ of biogas. Considering an investment cost on the electricity generation system of US$ 77,610.84, operating 10 h a day.

Table 2 shows the current property situation, in which the producer has been exclusively generating electricity.

By producing only electricity, the producer would be able to achieve in a 5-year investment amortization period a competitive price for electricity generation.

5. Discussions

According to Aneel [28], wind power production cost is US$ 54.19 MWh^{-1}, solar power is US$ 128.07 MWh^{-1} and the cost for energy from small hydro stations is US$ 34.48 MWh^{-1}; by comparing these prices with the electricity generation on the studied property one can verify that electricity generation with biogas as primary source is more feasible than wind and solar power electricity generation, however less feasible when compared to electricity generation from small hydro stations.

Studies on biogas electricity generation from swine waste are new [29,30], and economical related studies are still rarely done [31]. Studies made on biogas electricity generation from swine waste plants show that increasing the size of the plant would also increase installation and operating costs at the same rate regardless of the biodigester type installed.

Yiridoe et. al, [32], and Brown et. al, [33], in a study on the feasibility of biogas electricity generation for small dairy producers verified that it is not feasible, at a cost of US$ 0.12.kWh^{-1}. For small swine producers it also became not feasible to produce biogas, at a cost which is similar to that of the dairy producer US $0.12.kWh. [34] studied the home use of biogas in Ethiopia and found a 10% return rate for a plant capacity of 6 m³, using animal manure.

Table 1
Power (kW)/consumption (m³ h^{-1})/specific consumpition (m³ kW h^{-1}).

Date	Power (kW)	Consumption (m^3 h^{-1})	Consumption specific (m^3 kW h^{-1})
01/march/2011	70.4	47.6	0.67
02/march/2011	67.3	45.1	0.67
03/march/2011	67.3	45.1	0.67
04/march/2011	65.7	45.7	0.69
05/march/2011	60.5	41.2	0.68
06/march/2011	62.8	43.6	0.69
07/march/2011	66.8	45.2	0.67
08/march/2011	65.3	46.3	0.70
09/march/2011	68.8	46.9	0.68
10/march/2011	71.2	49.4	0.69
11/march/2011	59.5	43.7	0.73
12/march/2011	69.4	48	0.69
13/march/2011	63.9	45.5	0.71
14/march/2011	68.3	44.5	0.65
Avarege	66.22	45.55	0.68

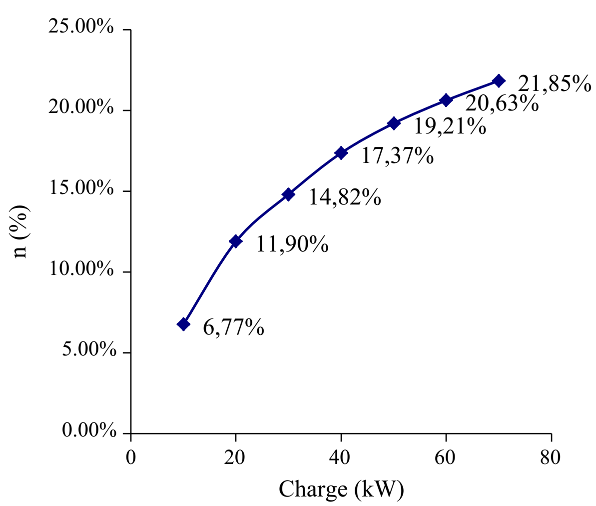


Fig. 7.

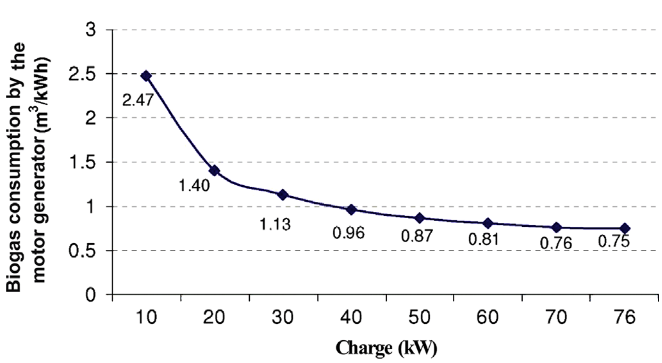


Fig. 8.

Table 2
Electricity production cost.

Payback period (years)	Cost of electricity (U.S. $ MWh^{-1}) in 10 h of operation of the motor-generator
5	60.00
10	10.00
15	4.92
20	0.98

Chynoweth [35] Walla and Schneeberger [36], analyzed the feasibility of biogas electricity generation through swine waste and found a mix of important variables: economic efficiency of anaerobic digestion, investment cost, cost of biogas units exploitation and methane production.

Kunz et. al, [37], when studying a swine waste treatment system, found that selling carbon credits reduces production costs between 14 and 18%. When installed in rural properties it is able to generate extra income with biogas and bio-fertilizers. This income can represent profit at an internal refund rate (IRR) varying between 6.4% and 28.4% a year, depending on environmental goals and project development.

6. Conclusion

With an amount of 4868 housed animals the property produces 586 m^3 day^{-1} of biogas, generating 800 kWh m^3 on 10 daily working hours of the engine-generator set.

For an amortization period of 5 years, the cost of electricity production is US$ 59.11 MW h^{-1} at the lowest possible investment interest rates. Currently at the property, biogas electricity generation is feasible because the sale of spare electricity generates US$ 68.96 per MWh. Investment return varies according to the price of the produced electricity sold and availability of power plant operation.

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